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SUMITOMO'S Nb_3Al J_c MEASUREMENTS AT THE SHORT SAMPLE TEST FACILITY

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Abstract:

A Sumitomo's Nb_3Al strand was heat treated in an IB3's furnace and tested at the SSTF of the TD. The I_c dependence on field and temperature was measured from 4T to 15T and from 3.5K to 4.5K respectively. A comparison in the J_c performance is given with respect to NbTi and Nb_3Sn. A parametrization is found in order to infer the J_c for applications at lower fields and higher temperatures.

1. INTRODUCTION

Despite its not being fully commercialized, especially in the high performance version, Nb_3Al offers in the design of a superconducting magnet an interesting perspective with respect to Nb_3Sn, thanks to its larger J_c strain tolerance. Also, Nb_3Al is expected to have higher T_c and H_{c2} values than Nb_3Sn, allowing for instance applications at higher temperatures.

In the Nb-Al system the stoichiometric A15 phase is stable only at high temperatures (*i.e.* above 1800^{o}C) and becomes depleted in aluminum at low temperatures. However, the A15 phase close to the stoichiometric composition can be formed at relatively low temperatures (*i.e.* 700^{o}C $\div$900^{o}C) when the dimension of the diffusion distance in the Nb/Al couple is reduced below 1 μm. This has been achieved by a powder metallurgy process and a composite process.

Sumitomo's 0.809 mm wire is a Nb/Al composite assembled using a modified jellyroll process. A thin Nb sheet, which is slit with controlled interconnection distances, is rolled up with an Al sheet in a jellyroll fashion, inserted in a copper container, and cold worked into a wire.

The composite was then wound on a grooved cylindrical barrel made of a Ti-6Al-4V alloy, and fixed on two removable Ti-alloy end rings. This set was heat treated for 50 hours at 750^{o}C in argon to form a wire having 96 filaments 53 μm in diameter, and a copper to non-copper ratio of 1.4.

2. J_c MEASUREMENTS

The present I_c measurements were carried out at the Short Sample Test Facility (SSTF) of the TD. At this facility, measurements at different temperatures and fields are obtained in a Variable Temperature Insert (VTI) within a 15/17 T magnetic cryostat [4].

After the reaction phase, the Ti-alloy end rings are replaced by copper rings, and the ends of the specimen are soldered to them. This set is mounted on the probe between two copper lugs of a cylindrical fixture, and the current is supplied to the sample by pressure contacts on the copper rings.

The experiment proceeds as follows: a current is ramped in the superconducting strand from zero to a maximum of 1020 Amps. The sample is immersed in liquid helium in the cryostat's VTI, which is itself located in a solenoidal magnetic field. Voltages are measured between different points of the sample by means of voltage taps. As long as the sample is superconducting – *i.e.* below critical temperature, T_c, and (upper) critical field, B_{c2} –, the voltage measured between two taps is close to zero. It slowly begins to increase during transition to the normal state and finally shoots up. The sample's power supply, the scanner, and the nanovoltmeter, as well as the instrumentation related to the magnetic cryostat, are controlled by a PC using LabView as a graphical interface. Figure 1 shows the measurements at 4.2K and 12T for a pair of voltage taps 50cm away from each other.

There are several criteria to define the critical current, I_c. Sumitomo refers to a critical field of 1μV/cm, which in Figure 1 corresponds to an I_c of 137A at 4.2K and 12T. The value quoted in their specifications is 133A. The more commonly used 10^{-14} Ω·m resistivity criterion, also shown on the plot, gives an I_c of 126A at the same temperature and field.

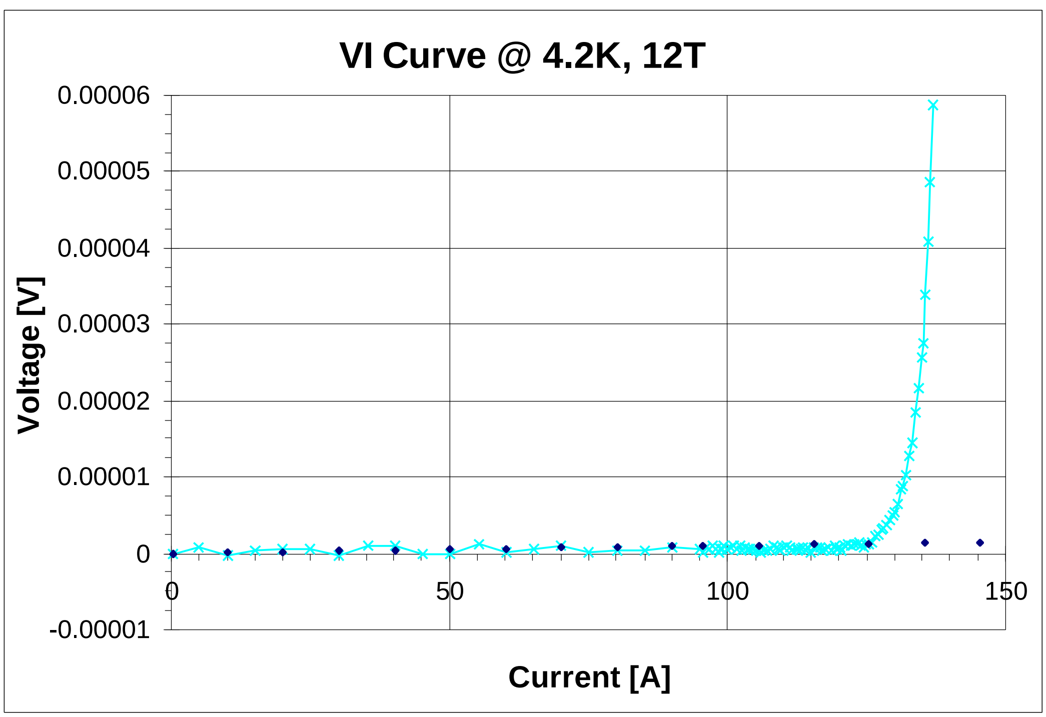

Fig. 1: VI curve at 4.2K and 12T. The line on the plot represents the 10^{-14}Ω·m resistivity criterion.

The I_c dependence on field and temperature was measured with the 10^{-14} $\Omega \cdot m$ resistivity criterion between 4T and 15T and at temperatures of 3.5K, 4.2K and 4.5K. The results are shown in Figure 2 and Table 1.

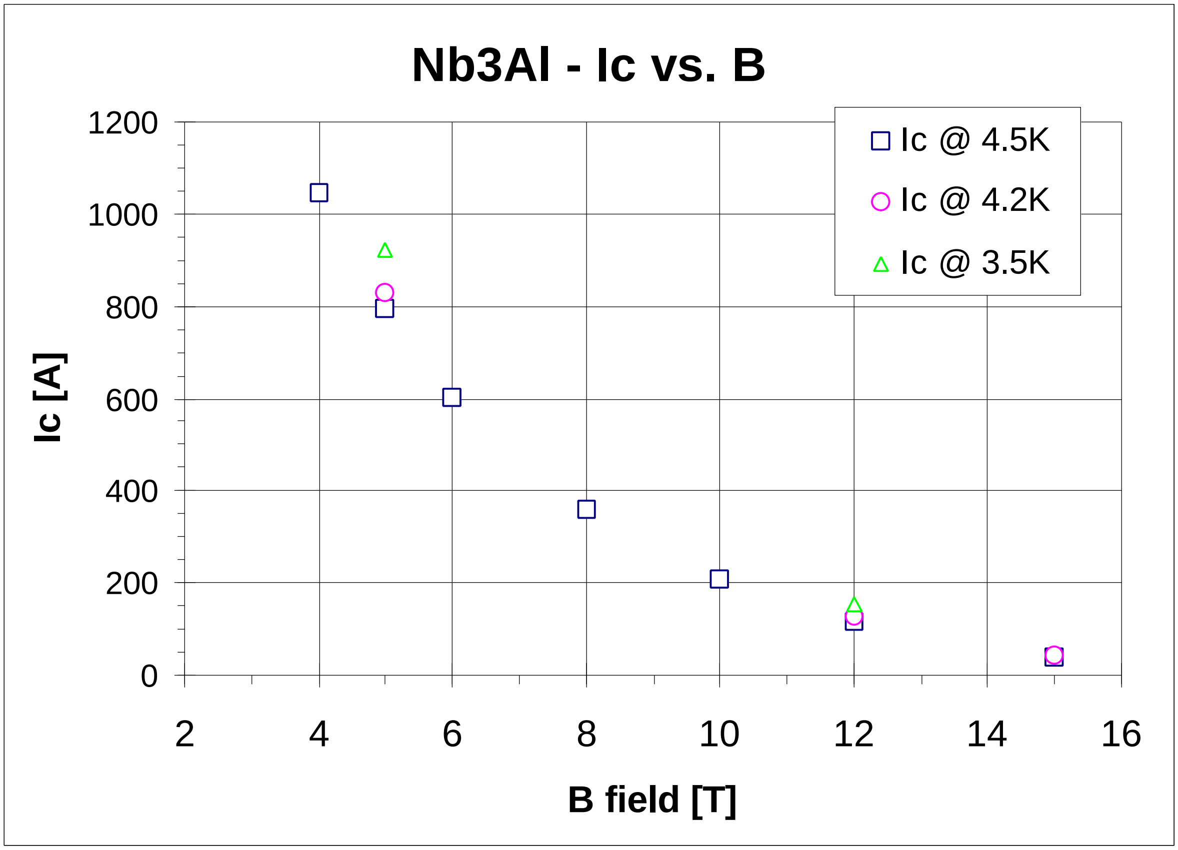

Fig. 2: I_c dependence on field and temperature between 4T and 15T and at temperatures of 3.5K, 4.2K and 4.5K.

B field [T]	Ic (ρ_c) @ 4.5K [A]	Ic (ρ_c) @ 4.2K [A]	Ic (ρ_c) @3.5K [A]
4	1044		
5	793	830	923
6	602		
8	357		
10	210		
12	117	126	153
15	37	41	

Table 1: Critical currents measured with the 10^{-14} $\Omega \cdot m$ resistivity criterion between 4T and 15T and at temperatures of 3.5K, 4.2K and 4.5K.

A comparison of the critical current density in the superconductor, J_c, of Nb_3Al, Nb_3Sn and NbTi composites is shown in Figure 3.

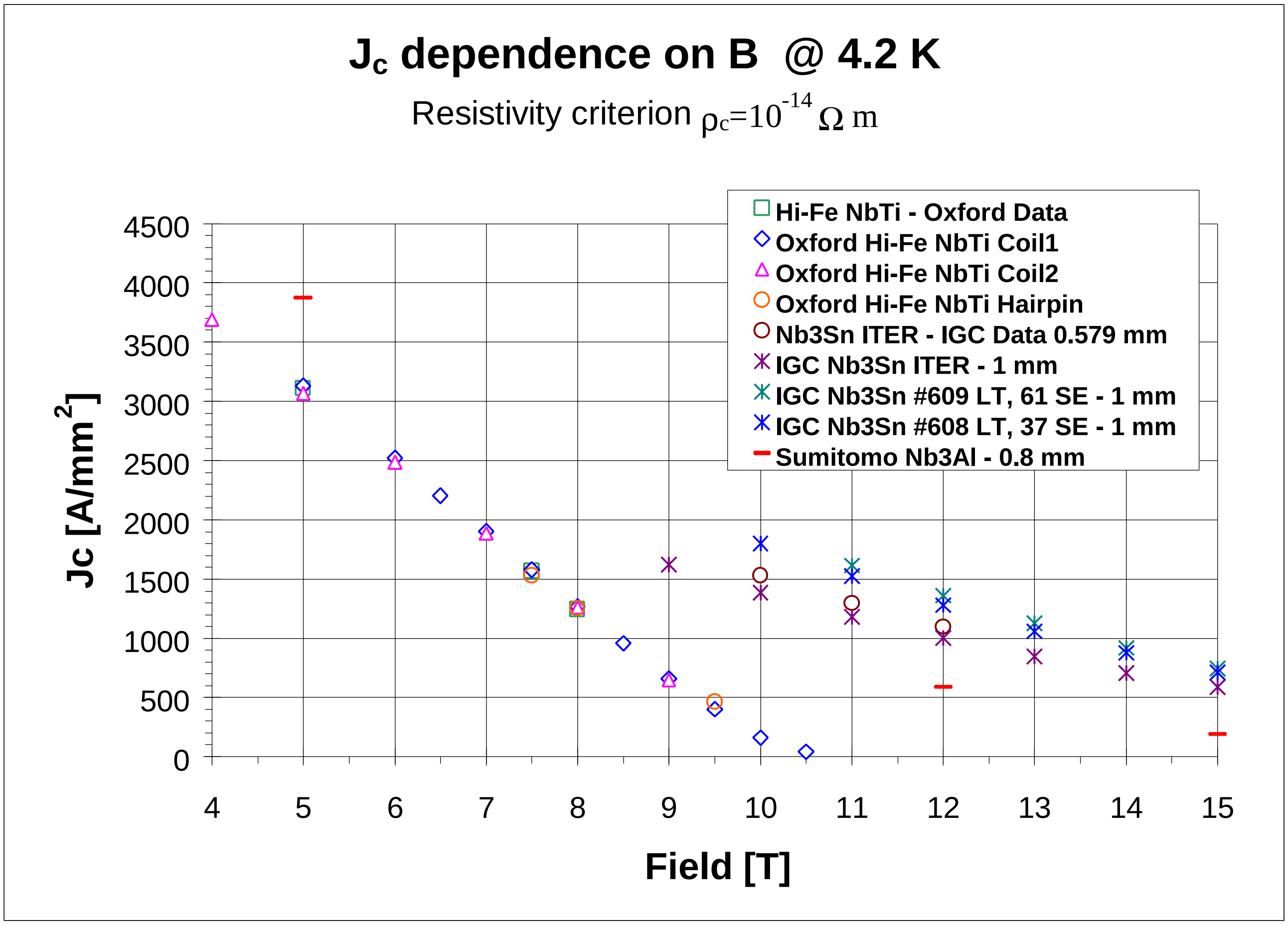

Fig. 3: Sumitomo's Nb_3Al performance in J_c with respect to NbTi and Nb_3Sn strands previously tested at 4.2K at the SSTF.

3. DERIVATION OF J_c AT HIGHER TEMPERATURES

To infer J_c outside the field and temperature data ranges where measurements were done, data were fitted with the following Nb_3Sn parametrization by Summers et. al. [2]:

$$J_c(B,T) = \frac{C_0}{\sqrt{B}} \left[1 - \frac{B}{B_{c20}\left[1-\left(\frac{T}{T_{c0}}\right)^2\right]} \right]^2 \left[1 - \left(\frac{T}{T_{c0}}\right)^2 \right]^2 \qquad (1)$$

where the strain in the superconductor was assumed zero. In equations (1), there are three fitting parameters: B_{c20}, the upper critical field at zero temperature, T_{c0}, the critical temperature at zero field, and C_0, a normalization parameter expressed in $AT^{1/2}mm^{-2}$. To a first approximation, these parameters can be derived from the data by using the following formulae [1], which are fairly applicable to all superconductors:

$$\begin{cases} B_{c2}(T) = B_{c20}\left[1-\left(\dfrac{T}{T_{c0}}\right)^{1.7}\right] & (2) \\ T_c(B) = T_{c0}\left[1-\dfrac{B}{B_{c20}}\right]^{0.59} & (3) \end{cases}$$

The I_c values at 4.5K shown in Figure 2 were linearly extrapolated to zero between 12T and 15T to give a B_{c2}(4.5K) of 16.4T. The I_c values at 5T and 3.5K, 4.2K, and 4.5K were linearly extrapolated to zero to give a T_c(5T) of 10.6K. These numbers were entered into equations (2) and (3), which were then solved as a system to obtain a B_{c20} of about 20T and a T_{c0} of about 13K. These values are close to those found in the literature for Nb/Al composites having undergone a one-step heat treatment at 700 to 900°C [3].

With the above values as a starting point for B_{c20} and T_{c0}, and C_0 normalized to a measured J_c of 3702 A/mm^2 at 5T and 4.5K, the J_c vs. B curve from parametrization (1) was compared at 4.5K with the data. The best result was obtained with the following parameters: B_{c20} = 20T, T_{c0} = 15K, and C_0 = 19003 AT$^{1/2}$mm^{-2}. This is shown in Figure 4. The difference between parametrization and data is less than 5% at 8T, and less than 2% at 4T.

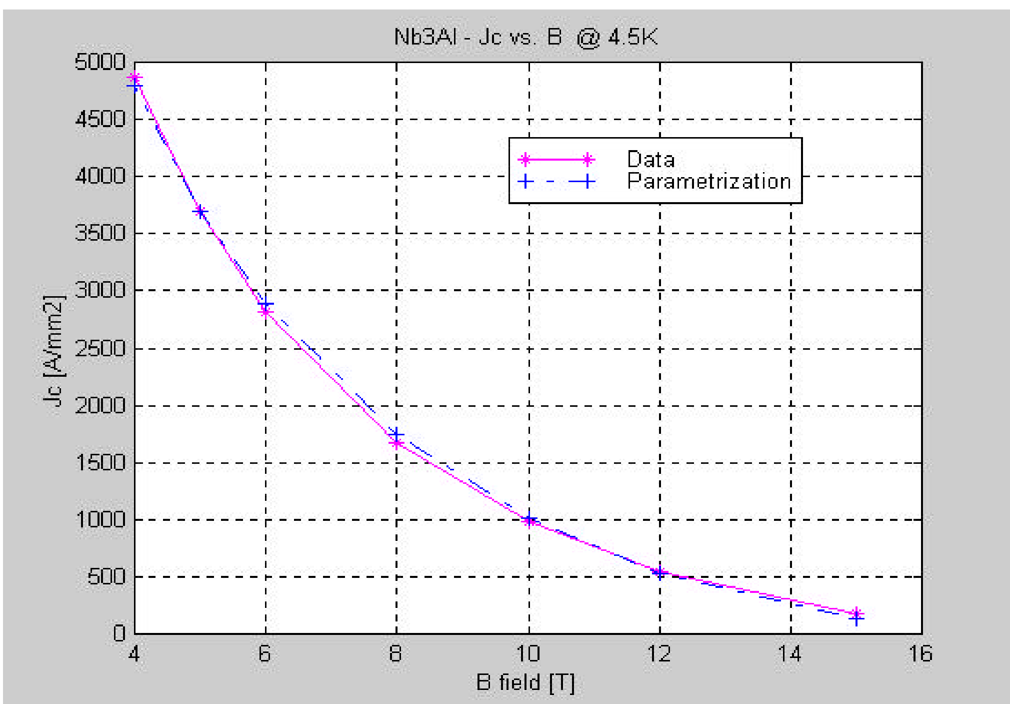

Fig. 4: Comparison at 4.5K of J_c data to parametrization (1).

The parametrized J_c found above can then be used at other temperatures, as shown in Figure 5. For instance, the J_c's infered at 1T are 14055 A/mm^2, 11040 A/mm^2, and 7516 A/mm^2 at 4.5K, 6.5K, and 8.5K respectively. In the Sumitomo's Nb_3Al strand, this translates to I_c's of 3010 A, 2364 A, and 1610 A respectively.

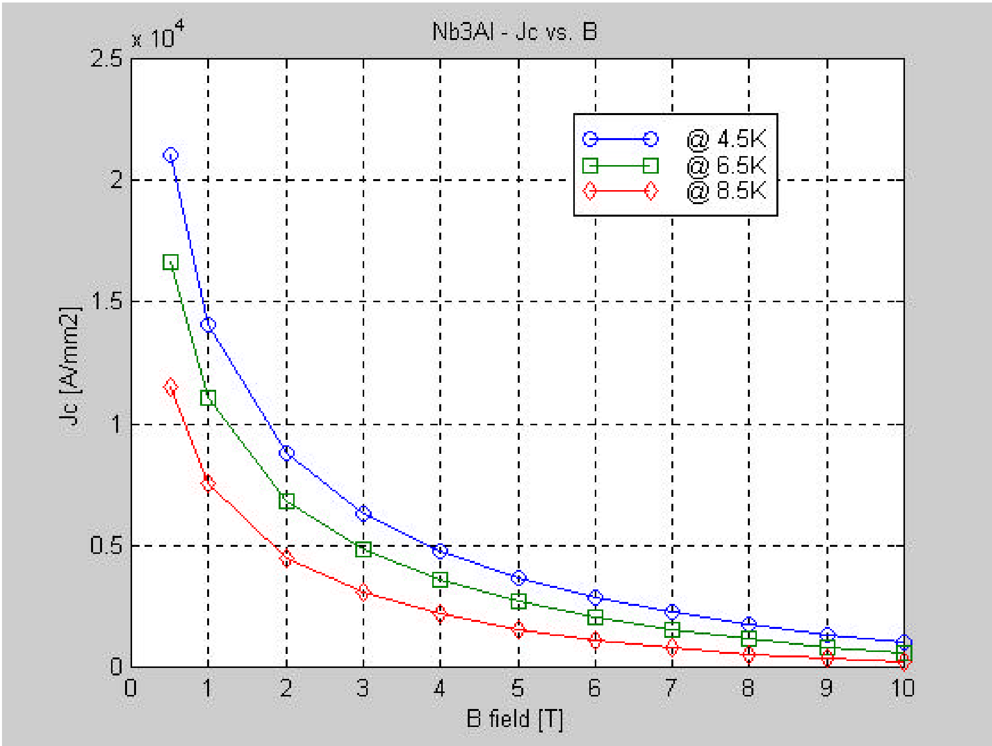

Fig. 5: Parametrized J_c at various temperatures.

4. CONCLUSIONS

Whereas Sumitomo's Nb_3Al composite in its present version (a one-step only heat treatment at low temperature) cannot yet compete with Nb_3Sn strands at high fields, it is already of some interest for applications at low fields and high temperatures.

REFERENCES

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